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A Global Optimization Approach Integrating Low Frequency Switching Harmonics Standard for Electric Actuators Design in Aircraft Electrical Networks: Harmonics/Weight Optimization

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Abstract *In aircraft applications, ensuring the power quality of the electrical system is one of the critical constraints during network equipment design. This task must be done in accordance with additional constraints like the global weight, cost and volume. In order to prevent high level disturbances in aircraft networks, international standards have fixed the conducted EMI levels that power converters are allowed to emit. On the other hand, respecting these standards at the design step requires analytical and semi-analytical models that are able to achieve a real system analysis and to develop optimized equipments adapted to the network requirements. In this paper we paved the way towards an anticipatory estimation of low frequency harmonics in a typical electrical actuator topology (Filter+Converter+Motor+Reductor). Several models (Three-phase PMW inverter, passive filter, gear reducers and a permanent magnet synchronous machine) were implemented in CADES software in order to find an optimal harmonics/weight Pareto solution using a deterministic or hybrid optimization approach allowing fast optimizations with a high number of parameters and constraints.*

Introduction

Power electronic devices associated to electric actuators become widely used in aircraft power system. Determining the best structure of any electrical system is always a challenging task for the designers. Indeed, this requires the optimization of the system with respect to the objective functions and to the constraints fixed by the standards. Thereby, unlike conventional methods that are based on individual component optimization, full system optimization becomes the recommended approach to develop adaptive equipment to the network requirements [1][2].

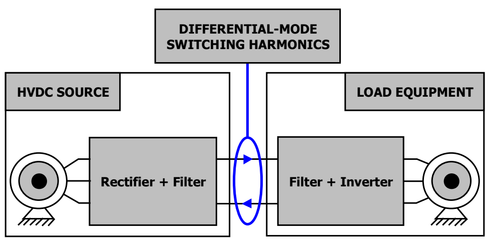

Fig. 1: Graphical diagram of the differential-mode current path in a typical power system

The typical structure shown in Fig. 1 gives a schematic illustration of the basic equipment massively used in aircraft applications. In order to estimate the switching harmonics in this kind of system, designers usually rely on temporal simulation tools. However, this task becomes more complicated when it is about to analyze the harmonics behavior relative to a parameter optimization (optimization of weight for example). In fact, even if it can lead to interesting results, using conventional power electronics simulators in the time domain can be complex and excessively time consuming. Thus, it is recommended to use analytical and semi analytical models for optimization applications that are able to achieve an acceptable accuracy level.

Considering Fig. 2, this paper addresses the case of load equipment optimization. The goal is to establish a link between the different equipment in order to minimize the total mass of the system while respecting the limits of low frequency switching harmonics tolerated by the standard. As we aim low frequency differential-mode disturbances, the parasitic elements are not taken into account.

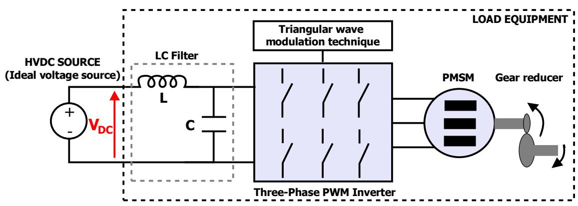

Fig. 2: Topology of the proposed electrical actuator

This paper is a first step towards a complete modeling of the power system. At this stage, only basic operating models are used for differential-mode switching harmonics estimation. All the optimizations were performed using CADES software [3] on which the models are implemented.

Only brief definitions and results are given in this abstract. Technical details will be given in the full paper.

Models of the equipment

A permanent magnet synchronous machine coupled with a gear reducer is used as a load for the power converter. These elements impose the torque and the rotational speed which are directly proportional to the frequency and the efficient value of the current delivered by the three-phase power converter system.

The following figure shows two examples of the same PMSM and gear reducer obtained for two different iterations during the optimization process.

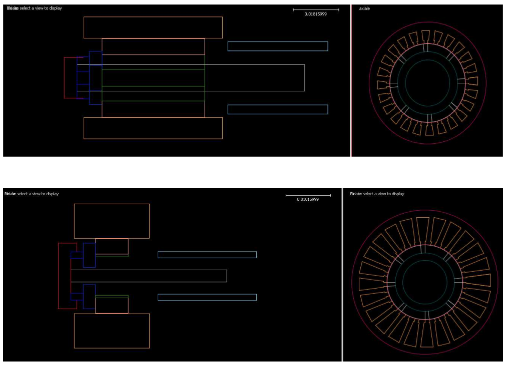

Fig. 3: Optimization results: Two different geometries for the same components

The previous elements impose the current amount delivered by the converter. We used the formulations described in [4] to build an analytical model for the three-phase PWM inverter. The analytical model is validated and the results are identical to those obtained by temporal simulation using PSIM software. At this stage of study, the conversion system mass (semi-conductors, connections, radiator …) is not taken into account.

From filtering standpoint, the system shown in Fig. 2 can be summarized as follows

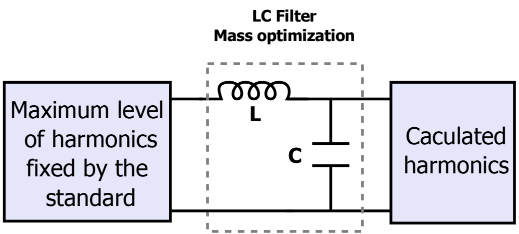

Fig. 4: Principle of filter optimization

An EMC input filter is required to comply with the standards. Nevertheless, it contributes significantly to the power converter system weight; hence optimized filter structure became a priority for aeronautic industry [5-7].

Fig. 5 shows the geometrical dimensions of the LC filter inductor. Two examples of the inductor geometry are shown in Fig. 6. As illustrated in Fig. 4, the optimization process is constrained by the standard which covers the frequency range of 10 Hz - 150 kHz.

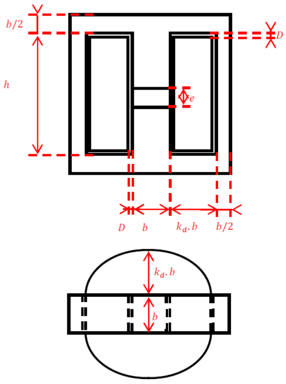

Fig. 5: Inductor geometry

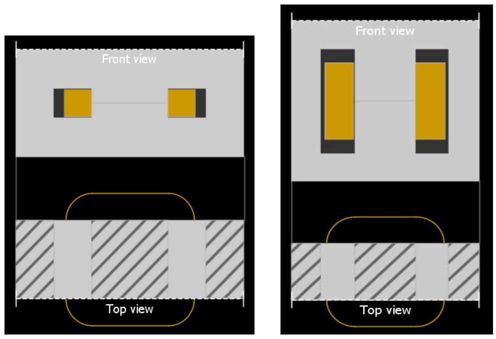

Fig. 6: Example of inductor optimization results

In the next section, results of harmonics/total weight optimization are shown. For this purpose, Pareto method is used in order to reach the Pareto optimal solution.

Overview on load equipment optimization results

A lot of progress has been done within the field of weight optimization. However, design problems are rarely mono-objective. In our case, we are looking for a trade-off between the two following objectives

$$f_1 = \text{Minimal harmonics}$$
$$f_2 = \text{Minimal weight}$$

In other words, we are searching for the curve that connects all the points under which there is no possible solution: it is called Pareto frontier curve (Fig. 7).

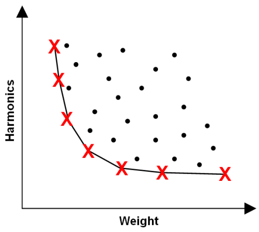

Fig. 7: Pareto frontier

As known, harmonics are spread at multiple frequencies. In order to have a practical representation of these harmonics we used the following formulation

$$THD_G = \frac{I\_harm\_eff}{I\_eff} \times 100$$

- THD_G is the total harmonic distortion;
- *I_harm_eff* is the efficient value of the harmonics;
- *I_eff* is the efficient value of the current including harmonics (DC + harmonics).

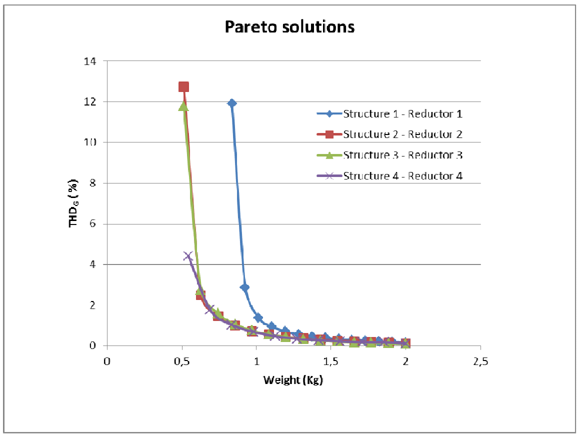

Fig. 8: Pareto frontier for different load cases

Four optimization results are shown in Fig. 8. Each curve is the result of the total load (Fig. 2) optimization. A different technology of gear reducer was used in each case. Among the four models examined here, the last one provides the best compromise harmonics/weight.

Conclusions

In this abstract, a brief overview of the optimization technique allowing the make a global optimization (EMI Standard Weight) for a typical aeronautical power system was given. The modeling and optimization steps will be detailed in the full paper.

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